MIAMI UNIVERSITY

GEOLOGY FIELD TRIP GUIDE

TO LOCALITIES ON INDIANA RT. 101 BETWEEN

BROOKVILLE
AND
LIBERTY

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and

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FIELD TRIP FOR
THE OHIO ACADEMY OF SCIENCE

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Leaders:

J.K. Pope, Professor Emeritus
W.D. Martin, Professor Emeritus
Mark Boardman, Professor

GUIDE TO SELECTED LOCALITIES IN THE RICHMOND GROUP OF FRANKLIN COUNTY, INDIANA

JOHN K. POPE

LOCALITIES:

STOP 1: GARR HILL SECTION ON INDIANA RT. 101, JUST SOUTH OF FAIRFIELD ROAD INSTERSECTION. WAYNESVILLE TO WHITEWATER FORMATIONS.

In Oxford, take Spring Street west. Continue west, cross the railroad track, the road becomes renamed Fairfield Road, continue west into Indiana, go through Old Bath and then New Bath and finally reach a "T" intersection. Turn left and then right on the first road. This leads to Indiana Rt. 101. Turn left on Rt. 101 and proceed a short distance to the Garr Hill Roadcut. Go to the bottom of the hill. Turn around, BE CAREFUL. Park about 1/3 of the way up the outcrop. We will walk to the bottom of the exposure and collect fossils slowly to the top of the cut.

STOP 2: SECTION ON CAUSEWAY ROAD ON THE WEST SIDE OF THE BROOKVILLE RESERVOIR. UPPER WAYNESVILLE AND LIBERTY FORMATIONS.

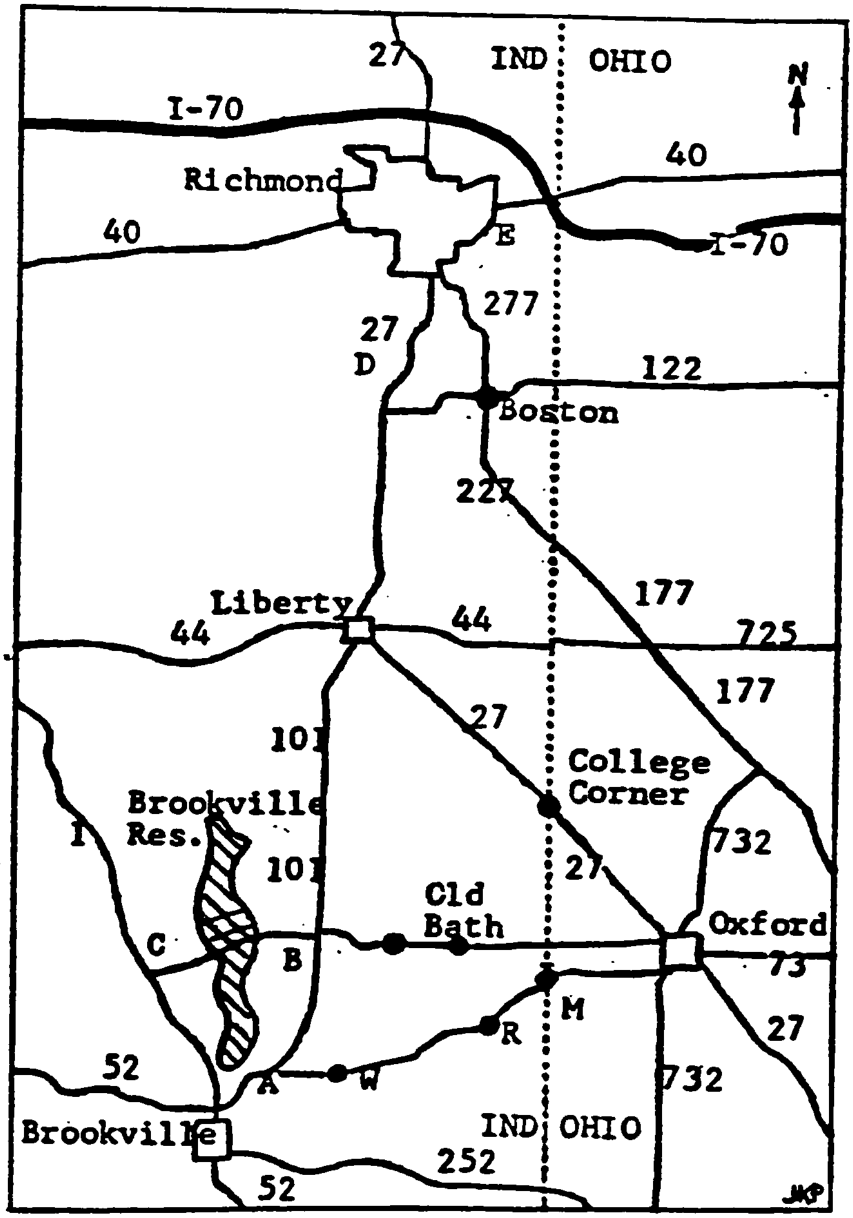
From Garr Hill drive north on Ind. Rt. 101 about a mile to a convenience store at the next right-hand intersection. STOP for snacks and a drink.

Continue north a short distance to Causeway Road on the left. Turn left onto Causeway Road. Proceed across the lake to roadcuts on both sides of the road. Park. This is a very productive fossil collecting site. Look carefully for trilobites. Collect a few richly fossiliferous slabs.

RETURN TO OXFORD BY 1:00, OR HAVE A PICNIC LUNCH AT THE PARK (MOUNDS ST. REC. AREA) OFF RTE. 101, NE OF BROOKVILLE, THEN STUDY THE BON WELL HILL SECTION

STOP 3: ARNHEIM FORMATION, WAYNESVILLE SHALE, AND LIBERTY FORMATION

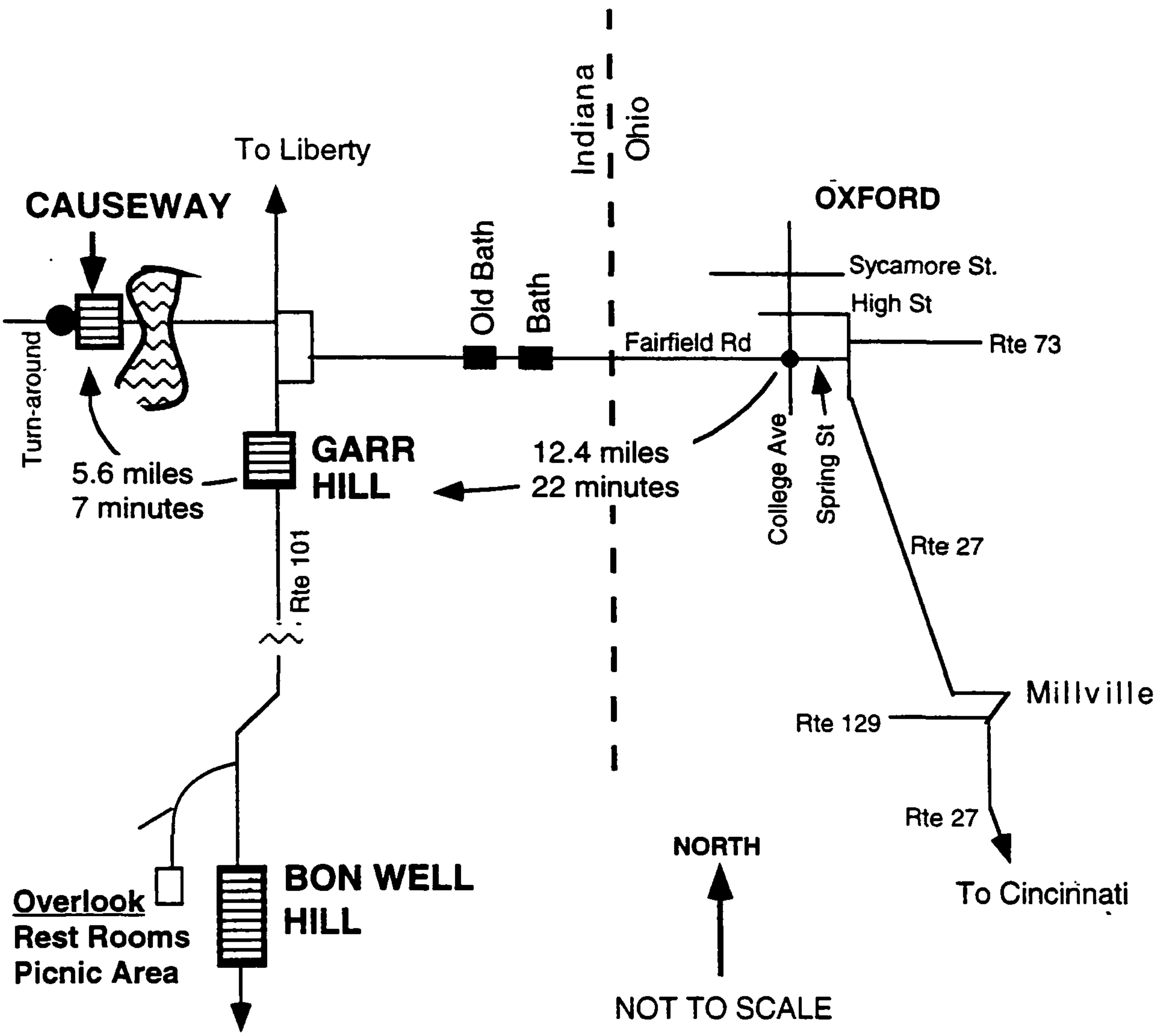
SOME OF THE DESCRIPTIONS OF THE ROADCUTS ON THE NEXT PAGES HAVE BEEN LIFTED FROM HAY, 1981, AND HAY, POPE AND FREY, 1981. THE STRATIGRAPHIC NAMES USED IN THOSE DESCRIPTIONS HAVE BEEN CHANGED TO CONFORM TO GENERAL USAGE.



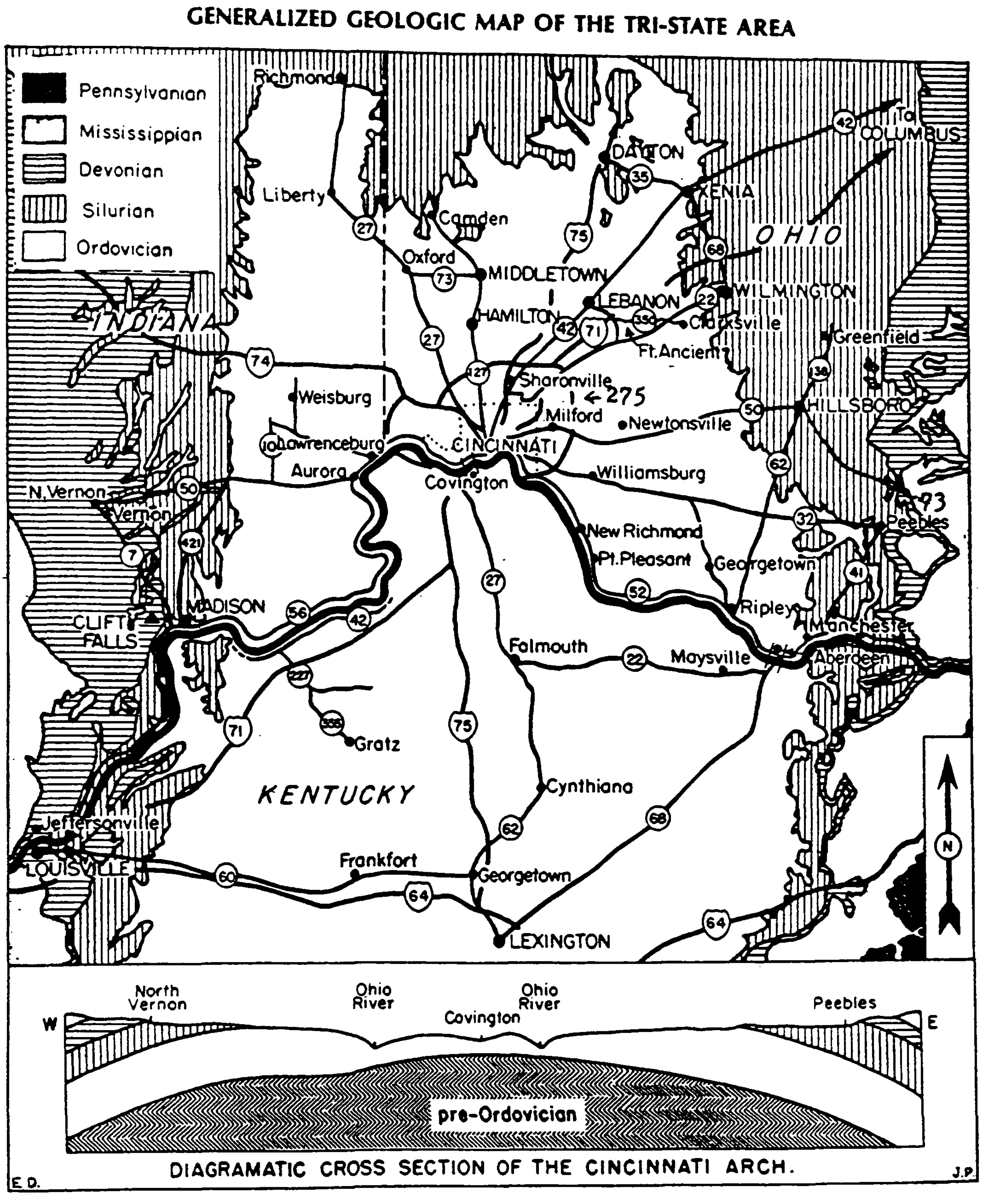
MAP 1--- PLEASE SEE MAP 2, PAGE 3--

Sections:
A- Bon Well Hill
B- Garr Hill
C- Causeway Road
D- Richmond South
E- Ordo.-Sil. Contact

Towns:
M- Mixerville
R- Raymond
W- Whitcomb


To Liberty
CAUSEWAY
Turn-around
5.6 miles
7 minutes
GARR HILL
Rte 101
Overlook
Rest Rooms
Picnic Area
BON WELL HILL
to Brookville
Old Bath
Bath
Indiana
Ohio
Fairfield Rd
12.4 miles
22 minutes
OXFORD
Sycamore St.
High St
Rte 73
College Ave
Spring St
Rte 27
Millville
Rte 129
Rte 27
To Cincinnati
NORTH
NOT TO SCALE

MAP 2--



MAP 3--GEOLOGIC-ROAD MAP, SHOWING MAJOR HIGHWAYS, TRI-STATE REGION. (Modified, Caster, Dalve & Pope, 1955).

TABLE 19-1 CALIBRATED GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	EVENTS IN THE HISTORY OF LIFE	OTHER IMPORTANT EVENTS
CENOZOIC	Quaternary	Recent (10,000)	Modern horse evolves in North America, then dies out	Ice Ages; Grand Canyon carved; Pacific Coast Ranges formed
		Pleistocene (1,000,000 to 2,000,000)	Earliest man	
	Tertiary	Pliocene (11,000,000)		
		Miocene (25,000,000)	Rapid spread and evolution of grazing mammals	
		Oligocene (40,000,000)	Earliest elephants	
		Eocene (60,000,000)	First primitive horses, rhinoceroses, and camels	
		Paleocene (70,000,000)	First primates	Uplift and folding of Western Geosyncline
MESOZOIC	Cretaceous (135,000,000)		Extinction of dinosaurs Great evolution and spread of flowering plants	Half of North America covered by seas Uplift of Sierra Nevada
	Jurassic (180,000,000)		First birds and mammals Dinosaurs at their peak Dinosaurs	
	Triassic (225,000,000)			Arid climates in much of western North America
PALEOZOIC	Permian (270,000,000)		Mammal-like reptiles	Ice Ages in Southern Hemisphere World climate much like today Deserts in western United States
	Pennsylvanian (305,000,000)		First reptiles Large insects	Widespread swamps, coal source Tropical climate in United States Uplift and folding of Appalachian Geosyncline
	Mississippian (350,000,000)			Widespread flooding of North America, limestone deposited
	Devonian (400,000,000)		Sharks abundant First amphibians First forests Trilobites	Filling of Appalachian Geosyncline and Western Geosyncline
	Silurian (440,000,000)		First air-breathing animals (scorpions) First land plants	Deserts in eastern and central U.S.
	Ordovician (500,000,000)		Trilobites at peak First vertebrates (fish)	Widespread flooding of North America by seas
	Cambrian (600,000,000)		Marine shelled invertebrates common First abundant animal fossils	
PRECAMBRIAN	PROTEROZOIC (2,500,000,000)		Marine invertebrates probably common; few with shells (1,200,000,000)	Glaciation-possibly worldwide Many geosynclines filled, uplifted, and eroded
	ARCHEOZOIC (4,500,000,000)		Earliest plants (marine algae) (3,200,000,000)	

NUMBERS REFER TO TIME IN YEARS B.P. (BEFORE PRESENT) SINCE THE BEGINNING OF THE ERA, PERIOD, OR EPOCH

AN ORDOVICIAN TIME SCALE

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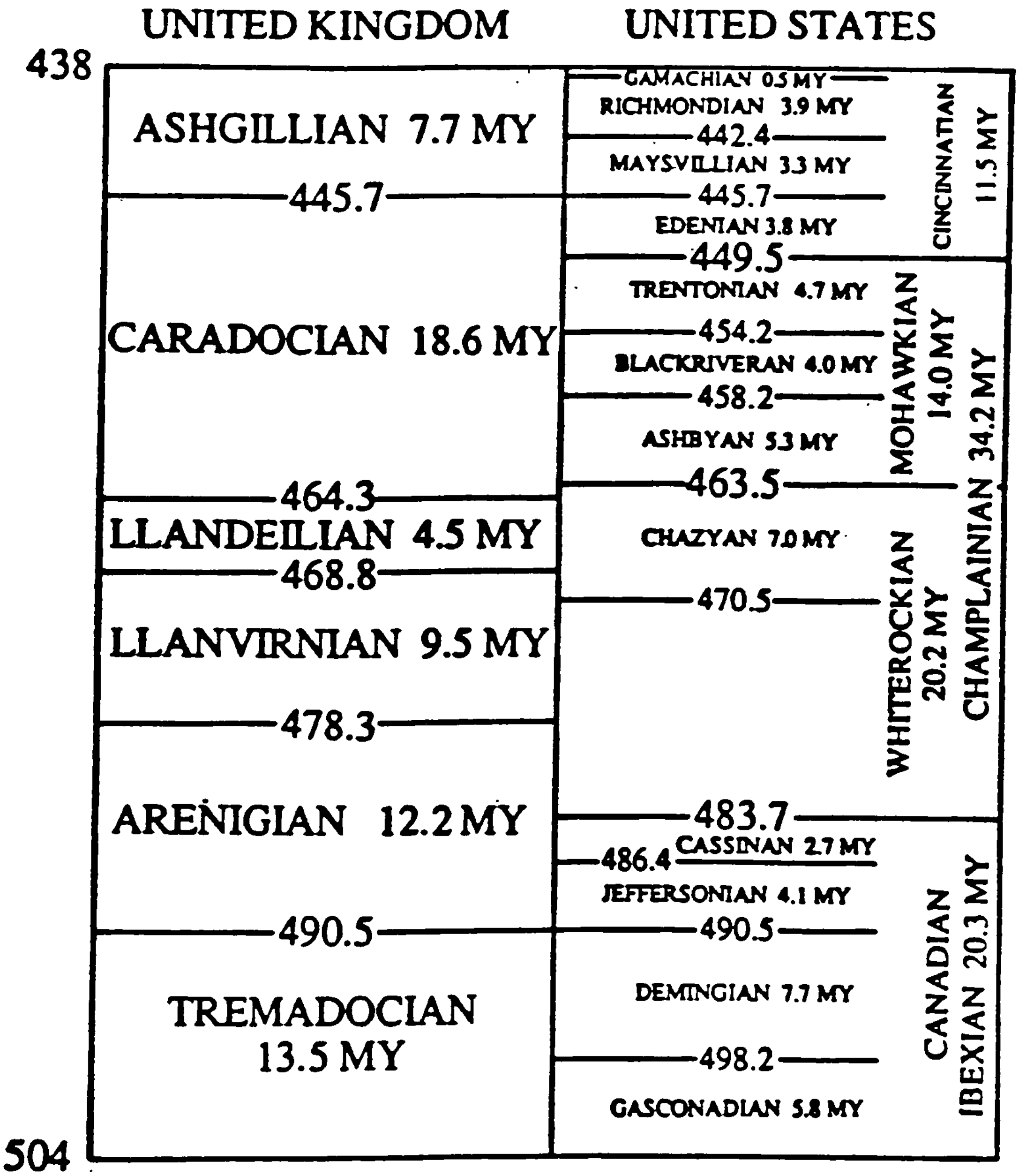
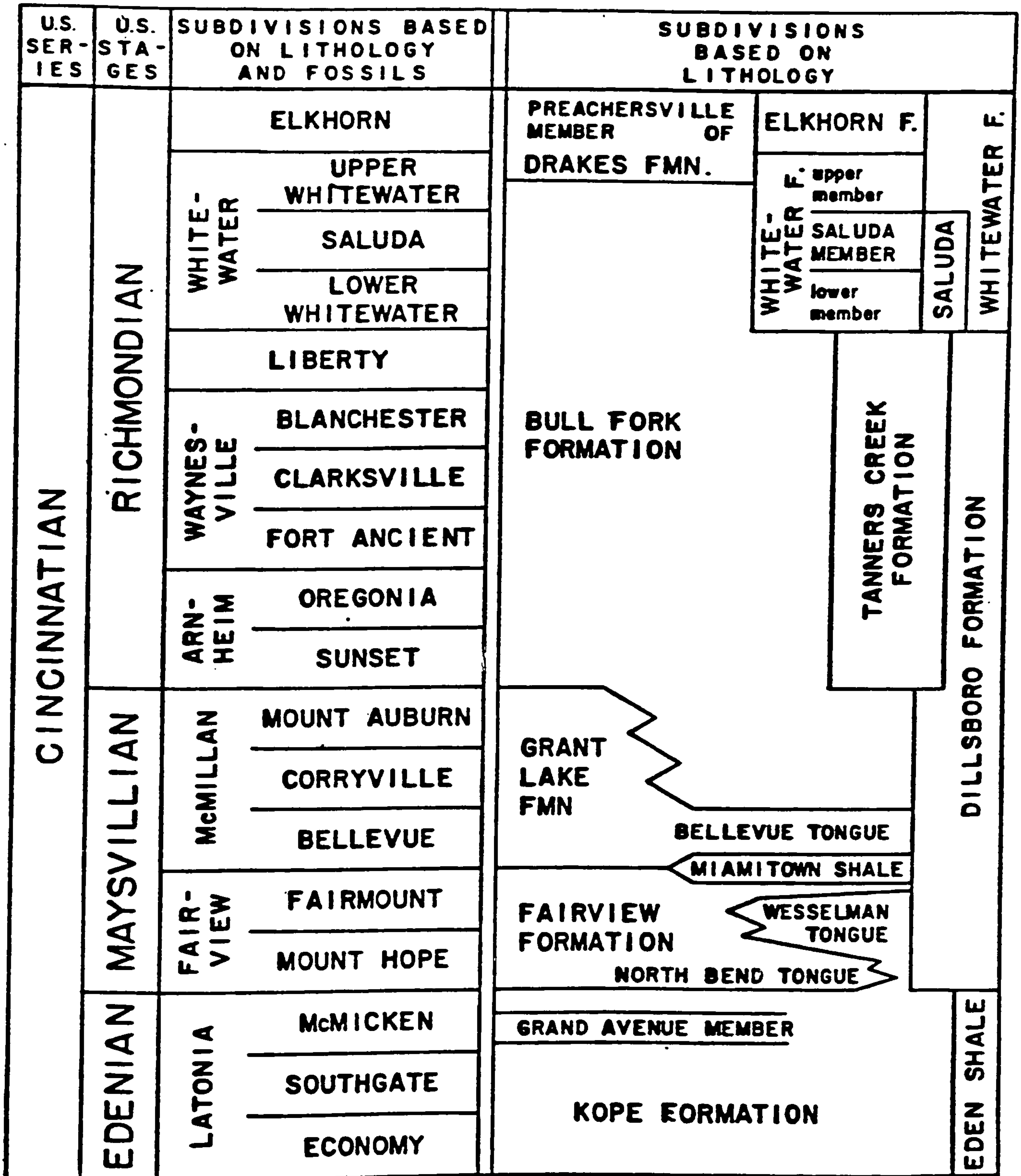
University of Minnesota, Minneapolis, MN, 55455



This time scale was generated from Sweet's 1984 CSS, Kunk and Sutter's T-3 date of 454.2, 438 Ma for the O/S boundary, 504 for the C/O boundary, Hintze's 1952 Ibex sections, and Ross and others, 1982.

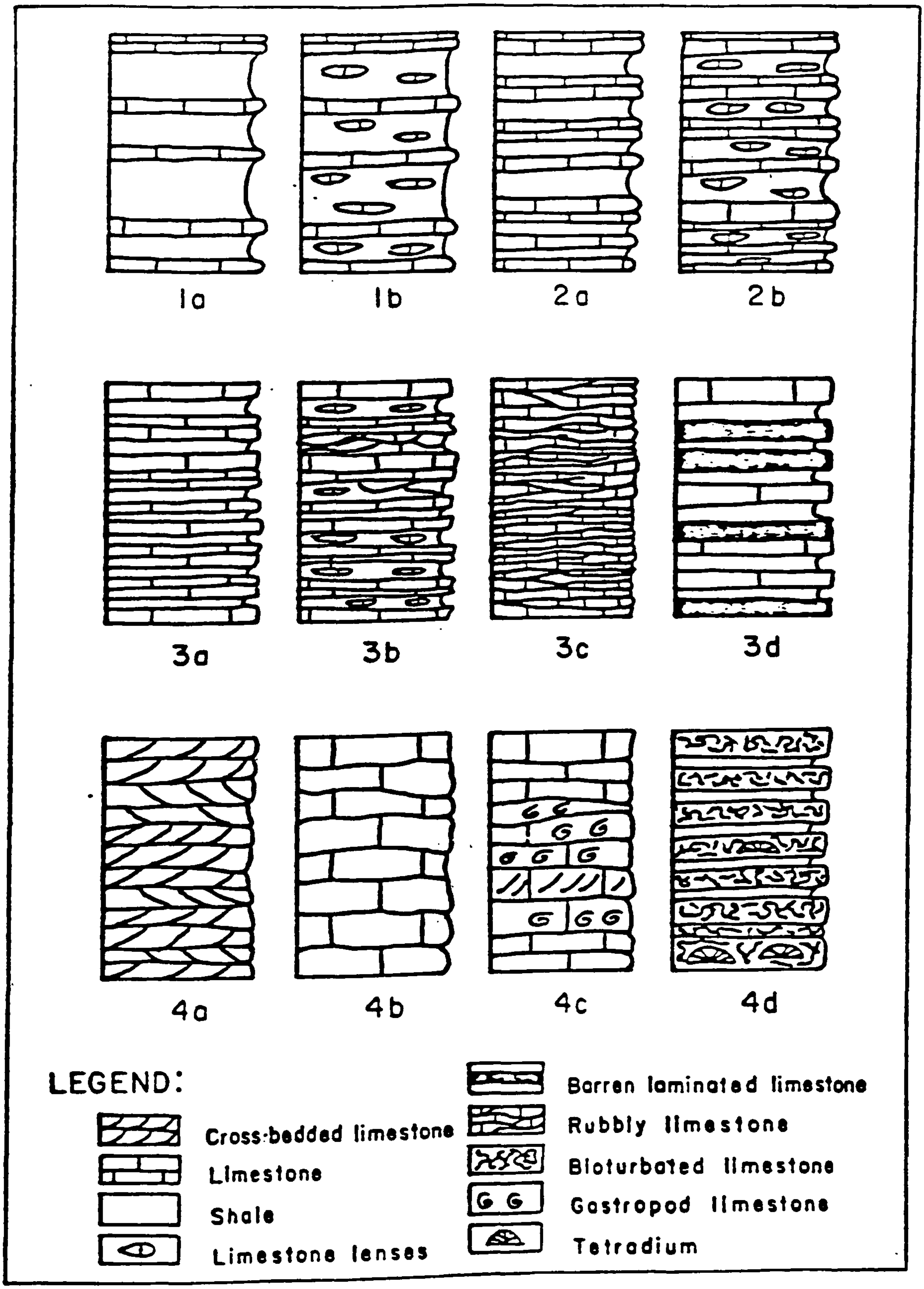
DAVIS, 1985

STRATIGRAPHIC NAMES USED IN THE TRI-STATE AREA



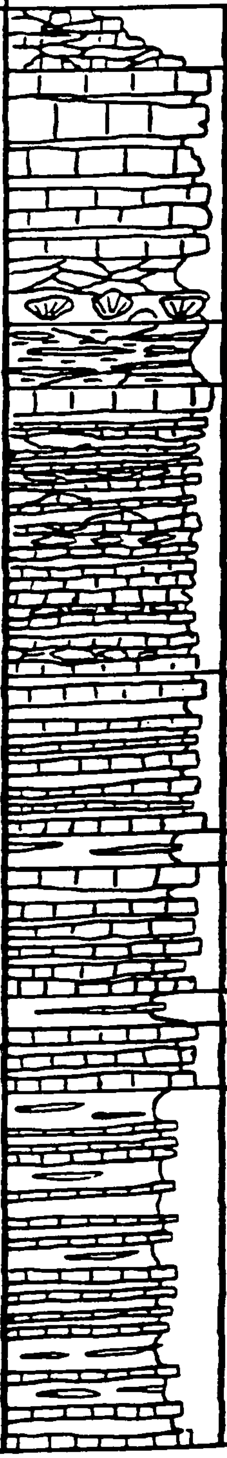
Those on the right are names that have been applied to rocks in the Ohio, Kentucky, and Indiana area. The different names do not necessarily represent different rock units nor their lateral relationships.

DIAGNOSTIC CHARACTERISTICS OF CINCINNATIAN LITHOFACIES		
GROUP 1 > 70% SHALE	1a	Well bedded; shale beds medium to thick, fissile to blocky; limestone strata generally thin. Some massive units of 100% shale. Low diversity fauna.
	1b	Shale strata medium to thick with rubbly, limy nodules and stringers. Fossils layered in shale. May have some regular limestone and shale strata as in 1a. Low diversity fauna.
GROUP 2 55-70% SHALE	2a	Thin limestone strata and thin to thick, fissile to blocky shale; well bedded. Fauna high diversity. Intermediate between 1a and 3a.
	2b	Well-bedded to rubbly to nodular limestone and limy shale. Fossils tend to be broken and sharp. High diversity fauna. Grades into 1b and 3b.
GROUP 3 LESS THAN 55% SHALE	3a	Thin to medium limestone strata and thin to medium, fissile to blocky shale; well bedded. High diversity fauna.
	3b	Well-bedded limestone with / without rubble or nodules. Shales limy. High diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, argillaceous, rubbly limestone and thin, limy shales. High diversity fauna.
	3d	Thin to medium limestone strata and thin to medium, fissile to blocky shale, well-bedded. Some beds micritic, laminated, burrowed, barren of large fossils, with trail-bearing silty tops. Silt ranges from >5% to <50%. Grades into 3a. High diversity, abundant fauna in some beds.
GROUP 4 MISCELLANEOUS	4a	Calcarenite with strong, high angle cross-bedding. Cross-bedding with bimodal dip. Little or no shale.
	4b	Thick to massive limestone beds with granule-size allochems. Grades into 4a.
	4c	Massive limestones with layers of different grain-size. Each layer well-sorted. Coarse layers may be gastropodal. Other layers contain highly fragmented allochems. Some cross-bedding. Ex., Marble Hill Bed Possible barrier bar origin.
	4d	Light gray thoroughly bioturbated limestone with low diversity fauna. Gastropods, ostracods, algae, cephalopods and tabulate corals principal fossils. Lagoonal or carbonate ramp origin. Ex., Saluda Beds

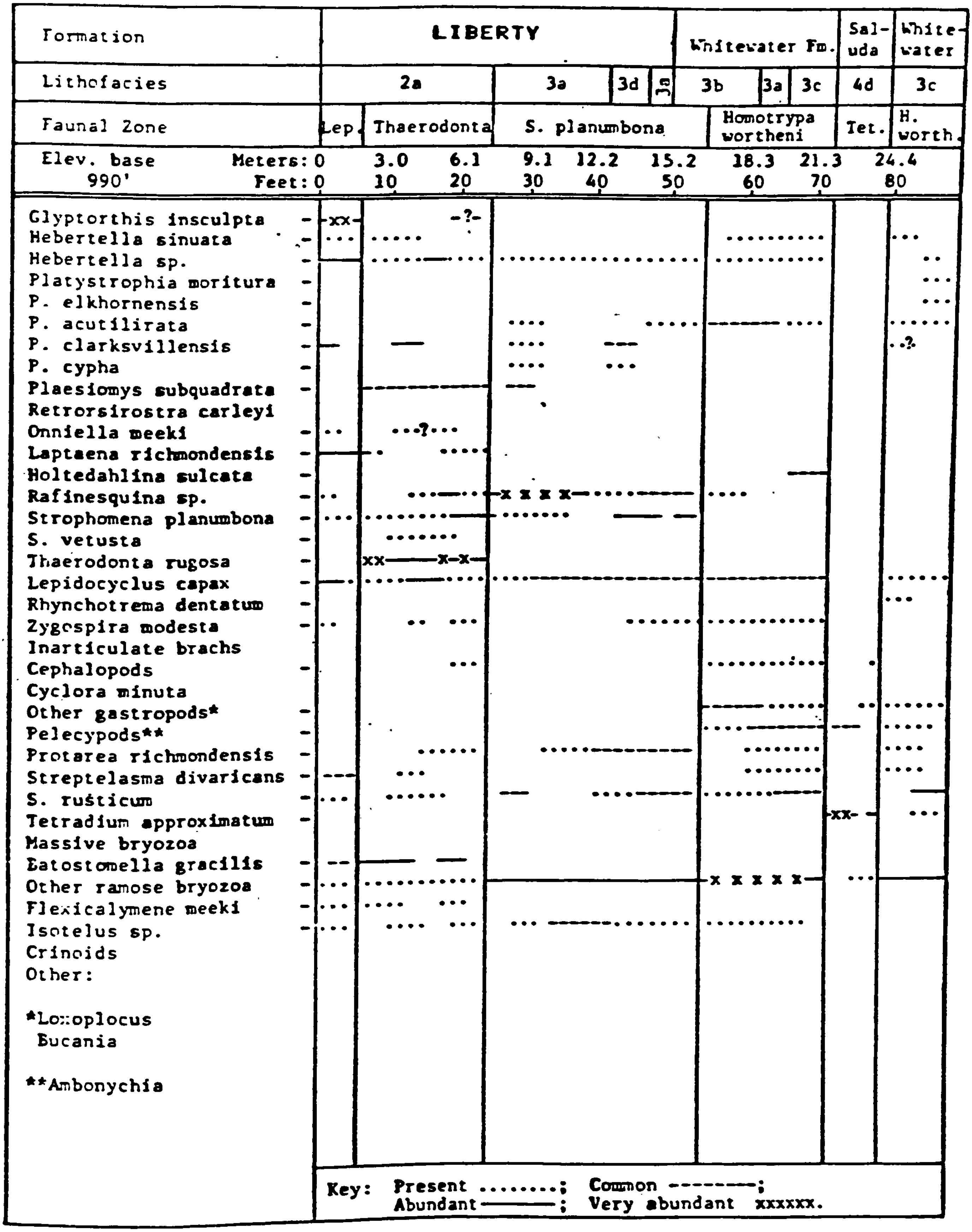


Illustrations of lithofacies types.

LITHO-FACIES	FAUNAL ZONE	METERS	GARR HILL SECTION, RT. 101, INDIANA GENERAL STRATIGRAPHIC DESCRIPTION	STRAT. UNIT
3C		27	Rubbly weathering; many fossils	WH.
4d	Tetradium	24	Massive to medium bedded, blocky fracturing, light gray lst. Poorly fossiliferous; scattered *Tetradium* colonies. Large *Isochilina* ostracods. Rare cephalopods. Bioturbated. *Tetradium* zone at base.	SALUDA
3c	Platystrophia acutilirata	21	Very limy shale.	WHITEWATER
3a 3b	Platystrophia acutilirata	18	Thin to medium bedded lst. with interbeds of calcareous, nodular shale. Some rubbly bedding. Bryozoa abundant.	WHITEWATER
3a 3d	Strophomena planumbona	15	Gray, finely crystalline, laminated, poorly fossiliferous, burrowed limestone. Vertical burrows probably *Skolithos*.	LIBERTY
3a	Strophomena planumbona	12	Predominantly shale.	LIBERTY
			Medium bedded limestone with thin shale partings. Prominent limestone band in this outcrop.	LIBERTY
		9	Predominantly shale. Lowest prominent lst. band.	LIBERTY
2a	Thaerodonta rugosa Leptaena	6 3	Highly fossiliferous limestone beds occurring in clusters separated by thick shales. Brachiopods diverse, abundant. Small trilobites in shales. Some bedding surfaces are hardgrounds. Abundant *Leptaena*, *Strophomena*, *Glyptorthis*, *Hebertella*, *Rafinesquina*, *Thaerodonta*, *Hiscobeccus*.	LIBERTY



GARR HILL SECTION. About 5 miles north of Brookville, IN, on Rt. 101.; Mt. Carmel Quadrangle. Elevation at base, 900 feet.


Formation
LIBERTY
Whitewater Fm.
Saluda
Whitewater
Lithofacies
2a
3a
3d
3b
3a
3c
4d
3c
Faunal Zone
Lep.
Thaerodonta
S. planumbona
Homotrypa wortheni
Tet.
H. worth.
Elev. base 990'
Meters: 0 3.0 6.1 9.1 12.2 15.2 18.3 21.3 24.4
Feet: 0 10 20 30 40 50 60 70 80
Glyptorthis insculpta
Hebertella sinuata
Hebertella sp.
Platystrophia moritura
P. elkhornensis
P. acutilirata
P. clarksvillensis
P. cypha
Plaesiomys subquadrata
Retrorsirostra carleyi
Onniella meeki
Laptaena richmondensis
Holtedahlina sulcata
Rafinesquina sp.
Strophomena planumbona
S. vetusta
Thaerodonta rugosa
Lepidocyclus capax
Rhynchotrema dentatum
Zygospira modesta
Inarticulate brachs
Cephalopods
Cyclora minuta
Other gastropods*
Pelecypods**
Protarea richmondensis
Streptelasma divaricans
S. rusticum
Tetradium approximatum
Massive bryozoa
Batostomella gracilis
Other ramose bryozoa
Flexicalymene meeki
Isotelus sp.
Crinoids
Other:
*Loxoplocus
Bucania
**Ambonychia
Key: Present ....; Common --------; Abundant ———; Very abundant xxxxxx.

STOP 1-- GARR HILL SECTION
WAYNESVILLE, LIBERTY, WHITEWATER AND SALUDA FMS.

This exposure presents the regressive phase of the third sedimentary cycle in the Cincinnatian Series. For more complete understanding, please read the text on the Bon Well Hill Section.

This outcrop presents several facies and faunal assemblages and it shows the regressive phase of the third sedimentary cycle in the Cincinnatian. This sequence is analogous to the Fairview-Bellevue sequence of the first cycle. The transgressive phase of the third cycle probably began with deposition of the muds of the Waynesville Shale. The peak of transgression, the turn-around so the speak, is found in facies 2a at the top of Bon Well Hill and at the the bottom of Garr Hill. Strata exposed in the the roadcut just south of Garr Hill occur in the top of the Bon Well Hill section.

At the base of the Garr Hill exposure, facies 2a has a very diverse and abundant fauna. Brachiopods have their highest diversity here. Horn corals first appear locally here and bryozoa, trilobites, echinoderms and mollusks are abundant. This assemblage suggests deposition on an open, stable shelf lacking stressful conditions. Abrasion of fossils, some of which are jumbled together into coquina-like beds, indicates periodic high-energy conditions.

The percentage of limestone increases upward, from 2a to 3a to 3d. This probably indicates shoaling so that sediment of the latter two facies may have been deposited near wave base. The contact between well-bedded rocks of the Liberty Formation and the rubbly rock of the Whitewater Formation is gradational here as at many localities. The gradational interval, 3b, is tentatively assigned to the Whitewater. The rubbly rock of facies 3c is well exposed at the very top of the outcrop.

The Tetradium coral biostrome and associate facies 4d of the Saluda Formation is well exposed in this outcrop. The massive Tetradium colonies perhaps served the function of wave-baffles on the margin of shallow lagoons in which the silty dolomites were produced that are typical of the Saluda farther south. At this locality, however, only the coral-zone and the burrowed micritic limestones of facies 4d occur. These burrowed limestones of 4d have an unusual fauna dominated by algae and small mollusks. This was possibly deposited around the edge of a lagoon just inside of the Tetradium baffle. Mudcracked Saluda sediments, not well displayed here, were deposited in very shallow water where locally they were intermittently exposed to the atmosphere.

Facies 3c, the typical facies of the Whitewater Formation, also represents very shallow conditions based on its stratigraphic association with the Saluda and its lithology. It may be envisioned as representing the relatively quiet interior of a shallow platform. Toward the margin of the platform, facies 3b was deposited and at the margin of the platform facies 3a accumulated. Off the edge of the platform in deeper water the muddier facies 2a was deposited. Superposition of these facies, as at this outcrop, indicates regression.

STOP 2-- CAUSEWAY ROAD SECTION
WEST OF RT. 101, ACROSS BROOKVILLE RESERVOIR

This section includes the upper part of the Waynesville Shale and most of the Liberty Formation. That is, the facies include 1a at the base and 2a and 3a farther up the outcrop (see the section on Garr Hill). Limestones containing abundant Thaerodonta rugosa are a convenient indication of the base of the Liberty Formation. Some of the limestones at the base of the Liberty Formation may be hardgrounds, with interesting erosional marks, burrows and incrustations. Watch for small trilobites in the shales at the base of the Liberty and lenses of crinoids farther up the hill. The top of the hill does not extend into the Whitewater Formation.

NOTES ?

STOP 3-- BON WELL HILL SECTION
ARNHEIM FM., WAYNESVILLE SHALE AND LIBERTY FM.

Time will not permit us to visit this outcrop on the field trip of June 15, 1991. Bon Well Hill is an interesting and an important section on Indiana Rt. 101 about 5 miles south of the Garr Hill Section . Perhaps you can visit this section individually on a later trip. It shows us the transgressive phase of the third sedimentary cycle in the Cincinnatian Series. There is a stratigraphic gap of about 2.5m between the top of this exposure and the base of the Garr Hill Section. This and the subsequent description of the Garr Hill Section have been abstracted from Hay, Pope and Frey, 1981.

Most of the Arnheim Formation at this outcrop is facies 2b, although the shales are less limy and the limestones less rubbly than usual. The other two facies in the Arnheim are 1b and a thin band of 3a. The latter is crossbedded calcarenite interbedded with sandy-textured, brown, phosphatic limestone at the top. The phosphatic grains are largely steinkerns of micromorphic mollusks. The Waynesville Shale contains two intervals of facies 1a separated by a middle band of facies 2a. There is a gradual increase in limestone in the upper half of the outcrop. The lower boundary of the Liberty Formation is not clearly marked.

The most interesting feature of this section is the nature of the contact between the Arnheim Formation and the Waynesville Shale and the cause of the abrupt facies change across the contact. The lower part of the Waynesville Shale is very sparsely fossiliferous and the few indurated beds in the shales are calcareous siltstones rather than bioclastic limestones. This easily recognized contact is a faunal as well as lithic boundary throughout southeastern Indiana and southwestern Ohio. It is possible that there is a disconformity between the calcarenites and the base of the Waynesville Shale or alternatively a disconformity just under the calcarenite. In the former case, the calcarenite would represent the culmination of regression and in the latter case the calcarenite would be a basal transgressive sandstone.

If there is a disconformity, then the Waynesville Shale is a transgressive unit in which the fine clastics were derived by erosion of muds stockpiled on coastal plains and deltas to the (present-day) east. The paucity of fossils in the lower shale unit is probably due to turbidity or unfavorable chemical conditions, perhaps brackish water, in a mud flat environment. Only infaunal and pioneering species occur in this interval.

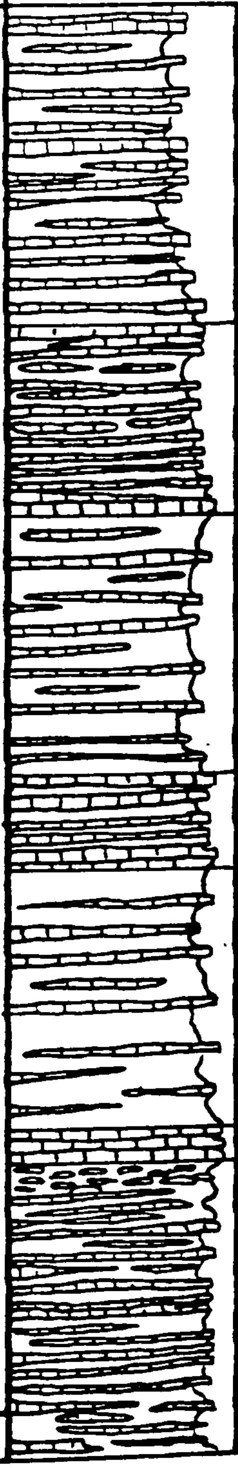
The upper part of the Waynesville Shale is much more fossiliferous than the lower unit although the fauna is rather low in diversity and highly dominated. Again, this faunal balance was probably controlled by turbidity. Mollusks are the most diverse part of the fauna, but brachiopods, while very abundant, amount to only a few species. There is a thin, light gray band, about half-way up the outcrop which contains trilobites and a diverse bivalve-cephalopod fauna.

The Arnheim-Waynesville boundary is interpreted to be the end of the second transgression-regression sedimentary cycle in the Cincinnatian. The Waynesville Shale is the transgressive beginning of the third cycle which ended with the regressive Whitewater-Saluda sediments seen at Garr Hill. These cycles probably are the result of waxing and waning of glaciers on Gondwana which produced worldwide changes in sealevel.

This section shows us the transgressive phase of the third sedimentary cycle in the Cincinnatian Series. The first cycle begins at the base of the Kope Shale and extends to the rubbly bedding of the Bellevue Member. The second cycle begins with the shale-rich interval in the base of the Corryville Member and extends, with a reversal following the Mt. Auburn, to the top of the Arnheim Formation. The Arnheim-Waynesville boundary is interpreted to be the end of the second transgression-regression sedimentary cycle. The Waynesville Shale is thus the transgressive beginning of the third cycle which ends with the regressive Whitewater-Saluda sediments seen at Garr Hill. The Elkhorn Formation therefore marks the beginning of a fourth cycle, but this is truncated, beheaded if you wish, by erosion which is seen as the Ordovician-Silurian disconformity. These cycles probably are the result of waxing and waning of glaciers on Gondwana which produced worldwide changes in sealevel.

The Waynesville Shale contains two intervals of facies 1a separated by a middle band of facies 2a. There is a gradual increase in limestone in the upper half of the outcrop. The Waynesville Shale is marked by plentiful Onniella meeki. The trilobite shale, otherwise called the Treptoceras zone or the "Butter Bed", is a thin, light gray band, found toward the middle of the outcrop. In addition to Flexicalymene, it contains a bivalve-cephalopod fauna, snails and occasional specimens of Tetradium and Labechia. The upper part of the Waynesville produces large clams, especially Anomalodonta and very large specimens of Rafinesquina that usually are called R. loxorhytis. The lower boundary of the Liberty Formation is not found positively at this site although Thaerodonta is found in weathered slabs at the top of the roadcut.

LITHO-FACIES	FAUNAL ZONE	METERS	BON WELL HILL SECTION, RT. 101, INDIANA GENERAL STRATIGRAPHIC DESCRIPTION	STRAT. UNIT
2a	Thaerodonta, Leptaena & Platystrophia	27 24	Rather regularly spaced lst. and shale units. Lst. strata about 7cm thick; shale units 15 to 20cm thick. Leptaena, Strophomena, Rafinesquina, Platystrophia and Hebertella locally abundant. Rare fossils found in this unit. Better seen at Garr Hill, 5 miles north.	LIBERTY
		21	Limestone and shale less regularly spaced than above.	WAYNESVILLE
1a	Onniella, Zygospira & Rafinesquina	18 15	High shale percentage. One thick (4") continuous lst. bed. Trilobites in 1/2m light gray shale zone. Locally abd. large Rafinesquina and slabs with abundant Onniella.	
2a		12	Prominent limestone band. Lst. increases upward in unit.	
1a		9	High shale percentage. Thin lst. strata may be silty and barren. Micro cone-in-cone found locally. Fossils uncom. except linguloids & bivalves.	
3a 1b	Cyclonema & Rafinesquina	6	Prominent ls. zone with brown shale. Abundant phosphatic micro-mollusks. Possible disconformity. Forms falls.	ARNHEIM
2b		3	Variable lithology. Lst. strata generally thin & even. Some bedding irregular. At top, zone of rubbly, nodular lst. Zone of Retrorsirostra near top. Some lst. bioturbated, burrowed.	



BON WELL HILL SECTION. About 1 mile north of Brookville, IN, on Rt. 101.; Mt. Carmel Quadrangle. Elevation at base, 747 feet.

BRIEF DESCRIPTION OF THE CINCINNATIAN SERIES (UPPER . ORDOVICIAN) OHIO, INDIANA AND NORTHERN KENTUCKY

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The Cincinnatian Series (Upper Ordovician) is approximately 200 m thick and is composed of alternating very thin to thin bedded, gray, fossiliferous limestones and blue-gray shales and/or mudstones. The proportion of shale or mudstone to limestone varies greatly within the sequence, being generally larger in the lower and upper parts. Single limestone beds are not laterally continuous but generally extend only for a few meters to several tens or hundreds of meters, pinching out within a shale section (Fig. 1).

Most bedding contacts are gradational, however, some are sharp and diastemic. Desiccation cracks occur in several of the formations and ripple-marked beds occur in all formations of the sequence.

The carbonate sediment which formed the limestones accumulated for the most part in and around benthic communities of organisms developed on the terrigenous mud bottom of a shallow epeiric sea. The model was that of a gently sloping carbonate ramp, open marine environment, with sedimentation generally below surf base. Higher salinities developed later in the period and near the end of the Ordovician Period tidal flats existed as a regression of the sea took place (Fig. 2).

The most abundant limestone is a coarse, poorly sorted rock containing 30 to 40% fossil allochems which were originally deposited with calcareous ooze. The ooze matrix has been largely converted by neomorphism to microspar and pseudospar. The average limestone is approximately a borderline rock between a biomicrosparrudite and a biospeudosparrudite, a skeletal wackestone or packstone, more commonly a wackestone.

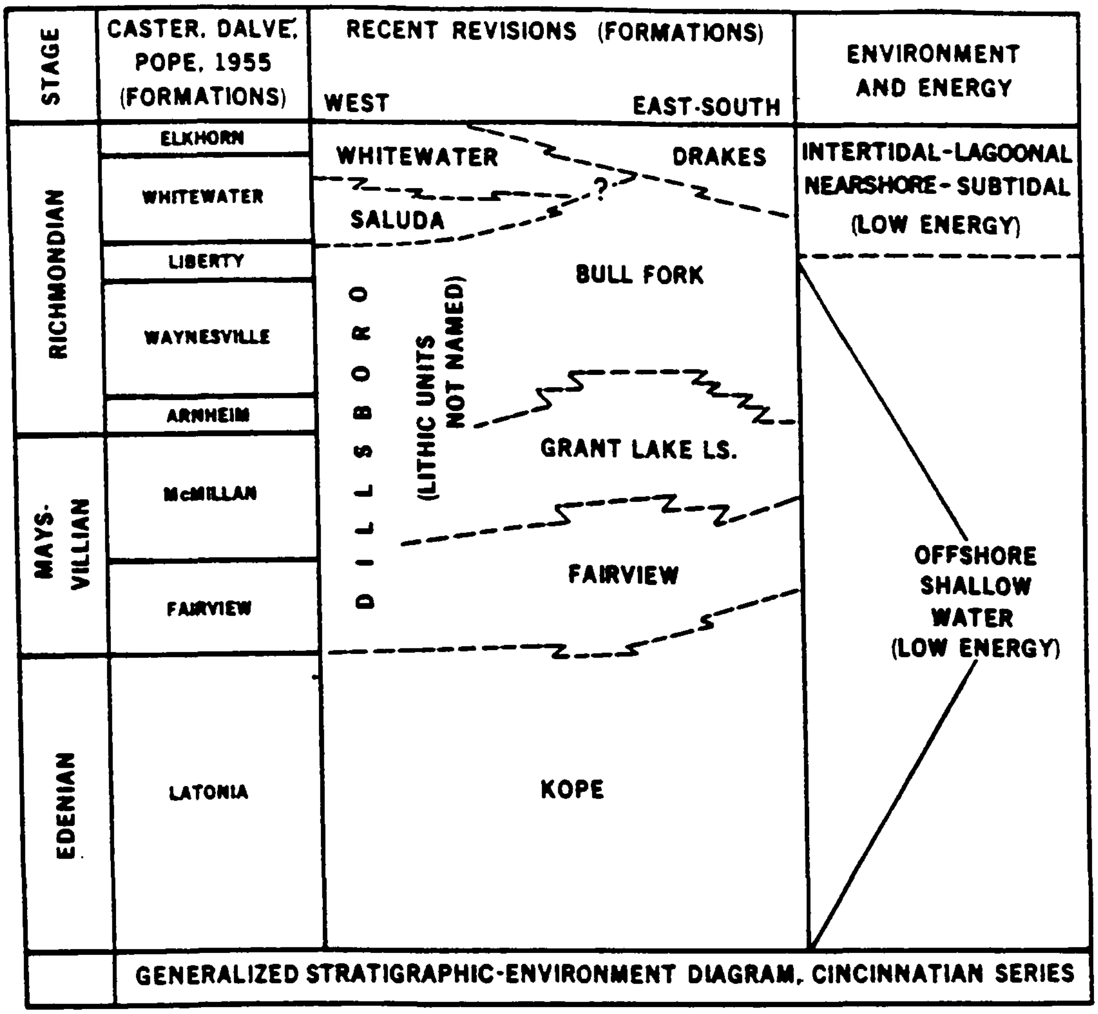
Martin (1975) reported that bryozoans and brachiopods, nearly equal in abundance, form about 60% of the allochems of the limestones. Crinoids form about 20% and trilobites nearly 10% of the allochems. Brachiopods and trilobites decrease appreciably in abundance upward in the section and algae, ostracodes and corals, which are uncommon through most of the sequence, are very common in the upper part. Dolomite forms less than 1% of the limestones of the lower part of the sequence but more than 5% of those of the upper part (Fig. 3).

Harris (1977) found that in some of the bad sequences at Bon Well Hill, the centers of the beds can be distinguished from the tops, bottoms, and margins of beds using certain variables and discriminant function analysis. Variables important in separation include neomorphic sparry calcite and echinoderms within the bed centers, and micrite, bryozoans and brachiopods within the tops, bottoms, and margins of the beds. An increase in faunal diversity from the bottoms to the centers of beds indicates rapid community succession. A decrease in faunal diversity from the centers to the tops of the limestone beds indicates community degradation.

A subtidal, terrigenous mud substrate was colonized by either bryozoans or by thin, flat brachiopods such as Onniella, or both. The accumulation of brachiopod valves provided a pavement upon which erect bryozoans could grow. Further stabilization of the substrate allowed crinoids and other organisms to become established (Harris and Martin, 1979).

A wave-current baffle was produced in the denser parts of the community by the abundant growth of bryozoans and crinoids creating low energy conditions favorable for the simultaneous accumulations of unsorted allochems and ooze. The community spread laterally as skeletal debris swept from atop the growing centers stabilized the peripheral muds. Carbonate accumulation terminated when mobilized, muddy, bottom sediment, thrown into suspension under storm conditions, settled and smothered the community (Fig. 4).

The model proposed for the accumulation of the carbonate sediments is independent of bottom topography and conditions of accumulation of terrigenous mud.



Martin (1975).

FIGURE 1-- Generalized stratigraphic-environment diagram of the Cincinnati Region. Lithostratigraphic nomenclature and approximate lateral and vertical relations from Sweet and Bergstrom (1971). The nomenclature of southeast Indiana is from Brown and Lineback (1966) and Hatfield (1968); of southwestern Ohio, from Ford (1967) and Osborne (1968); and of Maysville, Kentucky and adjacent Ohio, from Weiss and Sweet (1964) and Peck (1966). Lee (1974) proposed that the Waynesville Formation be considered a lithic unit in Ohio.

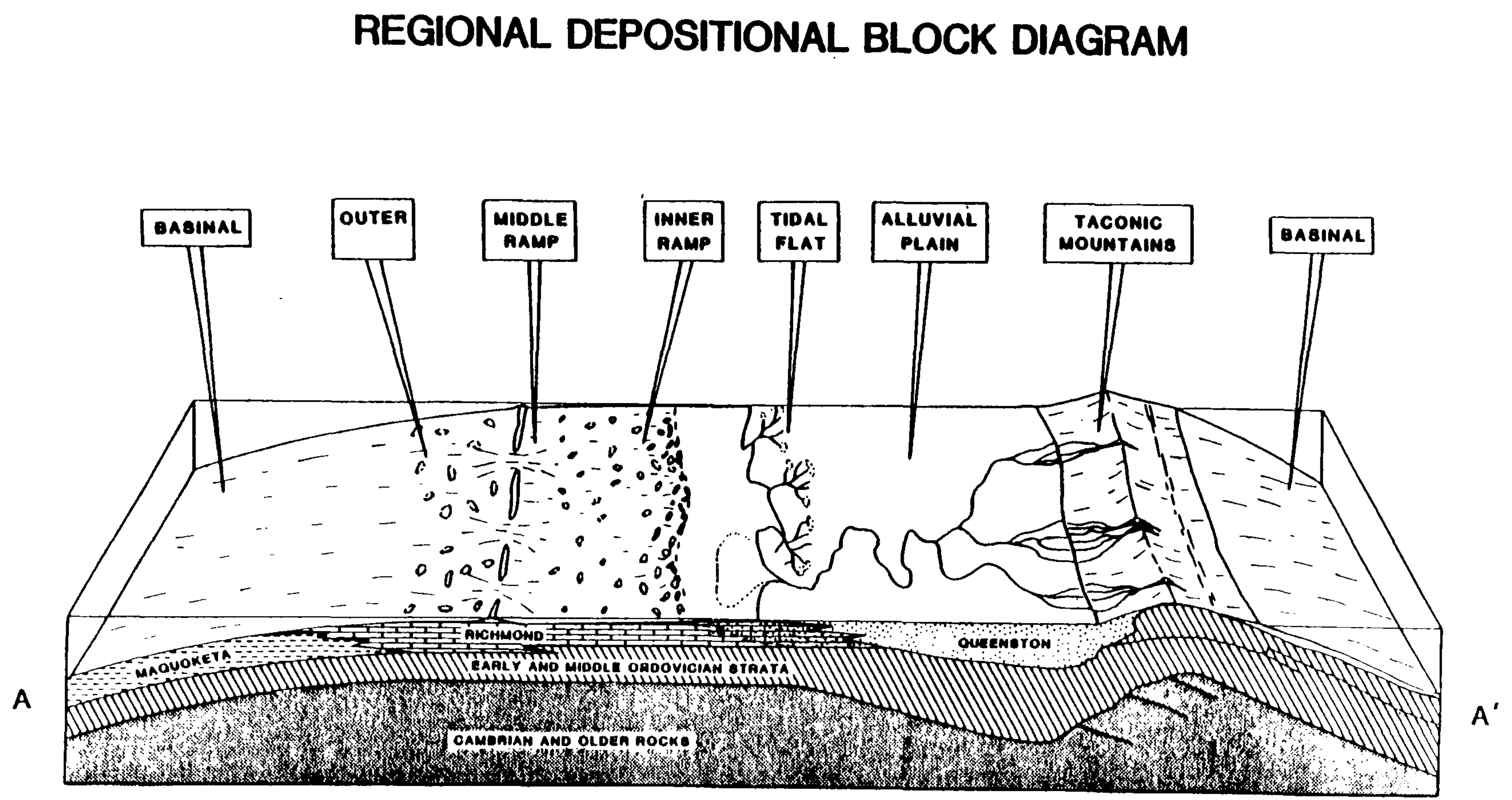
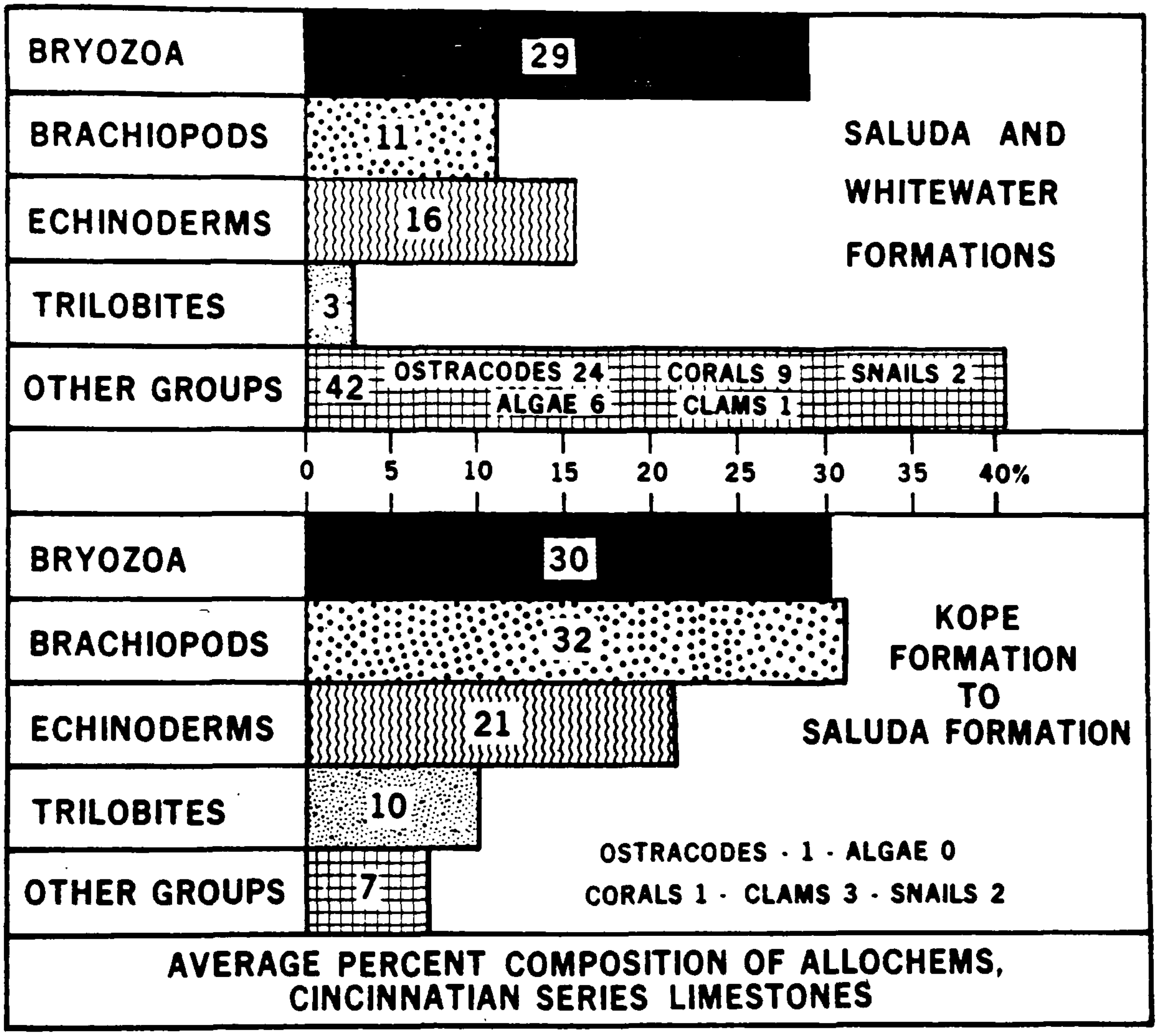


FIGURE 2-- Schematic cross section of Late Ordovician paleogeography and sedimentation bordering the Richmond carbonate ramp. (Adapted from Bird and Dewey, 1970). From Betz (1984).



MARTIN (1975).

FIGURE 3-- Average percent composition of the allochem fraction of faunal groups and algae in the Saluda and Whitewater Formations and the Kope to Saluda sequence.

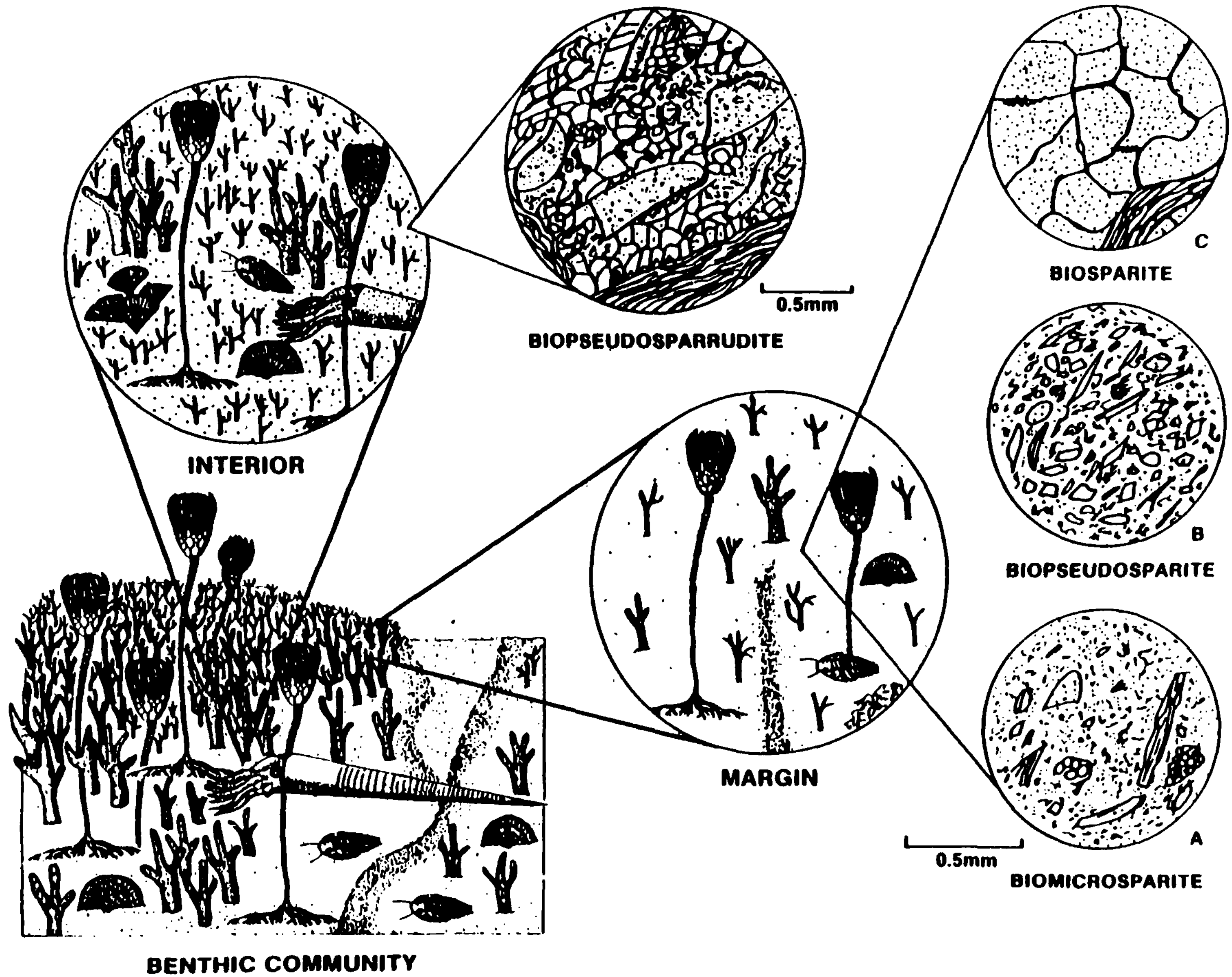


FIGURE 4---Relationship of Benthic Communities to rock types - Martin (1986).

REFERENCES CITED

BETZ, C.E., 1984, Facies analysis and depositional environments of the upper part of the Richmond Group (Upper Ordovician) Richmond, Indiana to Xenia, Ohio: M.S. thesis, Miami University, 159 p.

BIRD, J.M. and DEWEY, J.F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geol. Soc. of America, v. 81, pg. 1031-1060.

BROWN, G.D., JR., and LINEBACK, J.A., 1966, Lithostratigraphy of Cincinnatian Series (Upper Ordovician) in southeastern Indiana: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1018-1023.

CASTER, K.E., DALVE, E.A. and POPE, J.K., 1955, Elementary guide to the fossils and strata of the Ordovician in the vicinity of Cincinnati, Ohio: Cincinnati Mus. Nat. History, 47 p.

DAVIS, R.A., (ed.), 1985, Cincinnati fossils, an elementary guide to the Ordovician rocks and fossils of the Cincinnati, Ohio, region: Cincinnati Museum of Natural History, 60 p.

FORD, J.P., 1967, Cincinnatian geology in southwest Hamilton County, Ohio: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 918-936.

HARRIS, F.W., 1977, Textural and compositional variability in limestone beds from the Waynesville Formation (Upper Ordovician), Brookville, Indiana: M.S. thesis, Miami University, 142 p.

_______ and MARTIN, W.D., 1979, Benthic community development in limestone beds of the Waynesville (Upper Dillsboro) Formation (Cincinnatian Series, Upper Ordovician) of southeastern Indiana: Jour. Sed. Petrology, v. 49, p. 1295-1305.

HAY, H.B., 1975, Lithofacies classifications for the Cincinnatian Series (Upper Ordovician), southeastern Indiana: unpubl. M.S. thesis, Miami University, Oxford, Ohio, 147 p.

________, 1977, Cincinnatian stratigraphy from Richmond to Aurora, Indiana, p. I-1-I-34. In: Biostratigraphy and paleoenvironments of the Cincinnatian Series, southeastern Indiana, J.K. Pope and W.D. Martin (eds)., Seventh Ann. Field Conf. of Gt. Lakes Sec., Soc. Econ. Paleont. Mineral. (Dept. of Geology, Miami University, Oxford, Ohio, 45056) (Reprinted, 1986).

________, 1981, Lithofacies and formations of the Cincinnatian Series (Upper Ordovician), southeastern Indiana and southwestern Ohio. Ph.D. dissertation, Miami University, 236 p.

________, POPE, J.K. and FREY, R.C., 1981, Lithostratigraphy, cyclic sedimentation, and paleoecology of the Cincinnatian series in southwestern Ohio and southeastern Indiana, p. 73-86. In: Geol. Soc. American Cincinnati, 1981 Field Trip Guidebooks, v. 1: Stratigraphy, sedimentology, T.G. Roberts (ed.).

LEE, G.B., 1974, Lithostratigraphy of the Cincinnatian Series (Upper Ordovician) from Maysville, Kentucky to Dayton, Ohio: M.S. thesis, Miami University, 127 p.

MARTIN, W.D., 1975, The petrology of a composite vertical section of the Cincinnatian Series limestones (Upper Ordovician) of southwestern Ohio, southeastern Indiana, and northern Kentucky: Jour. Sed. Petrology, v 45, no. 4, p. 907-925.

________, 1986, Petrology of the Cincinnatian Series limestones (Upper Ordovician) of Indiana and Ohio: In: Biostratigraphy and paleoenvironments of the Cincinnatian Series, southeastern Indiana, J.K. Pope and W.D. Martin (eds.), Seventh Ann. Field Conf. of Gt. Lakes Sec., Soc. Econ. Paleont. Mineral. (Dept. of Geology, Miami University, Oxford, Ohio, 45056). Conference, 1977.

OSBORNE, R.H., 1968; The American Upper Ordovician standard, IX. Bedrock geology of eastern Hamilton County, Ohio: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 2137-2152.

PECK, J.H., 1966, Upper Ordovician formations in the Maysville area, Kentucky: U.S. Geol. Surv. Bull. 1244-B, 30 p.

SWEET, W.C. and BERGSTROM, S.M., 1971, The American Upper Ordovician standard. XIII. A revised time-stratigraphic classification of North American Upper Middle and Upper Ordovician rocks: Geol. Soc. America Bul.., v. 82, p. 613-627.

WEISS, M.P., and SWEET, W.C., 1964, Kope Formation (Upper Ordovician): Ohio and Kentucky: Science, v. 145, no. 3638, p. 1296-1302.

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